# MACRO DIVERSITY COMBINING SCHEMES FOR MULTICAST TRANSMISSION IN HIGH-SPEED CELLULAR NETWORKS

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Abstract: In this paper, we study the transmission of data destined for several users on the radio interface using the *multicast* mode, an interesting alternative of the conventional *unicast* mode. In the multicast mode, a packet is sent simultaneously to several terminals in the same cell. We consider different techniques of macro diversity, namely Selective Combining (SC) and Maximal Ratio Combining (MRC).

We develop an analytical model that allows the computation of the mean bitrate for both multicast and unicast schemes. We use a scheduler that allocates bandwidth to mobiles according to their instantaneous channel quality. In this context, we propose an efficient user clustering considering their average radio channel quality. The study shows that macro diversity improves the transmission performance especially for pure multicast.

## 1 INTRODUCTION

Packet scheduling is the functionality that distributes radio resources between users. Intensive research has been conducted on the performance of unicast schedulers in cellular networks (*e.g.* (Al-Manthari et al., 2006), (Liu et al., 2003)). During a service session, users may experience different channel conditions from a Transmission Time Interval (TTI) to another. The packet scheduler uses the reported channel qualities and chooses at each TTI the user to serve with the suitable modulation and coding scheme.

Multicast services have drawn a lot of attention recently. MBMS (Multimedia Broadcast/Multicast Service) is currently specified in the 3GPP recommendation. However, the focus is on the access and core network rather then on the radio interface. The conventional way to manage multicast services on the latter interface is to duplicate transmissions to the different User Equipments (UEs). This may however considerably waste radio resource if several users in the same cell are registered to the same service as only one user is served during a TTI. In this paper, such an approach is called multiple-unicast. An interesting alternative is to really send a given packet to several users at the same time. In order to avoid packet losses, the multicast scheduler must adapt the transmission bitrate to the mobile that has the lowest Signal to Noise Ratio (SNR). It is noteworthy that other multicast schedulers can be used such as Multicast Proportional Fairness (MPF) and Inter-group Proportional Fairness (IPF) (Won et al., 2007). However, packet losses are frequent with these algorithms and resulting retransmissions may decrease the system performance.

In a previous paper (El Heni and Lagrange, 2008b), we have studied multicast and multiple-unicast for several users in the same cell. It was shown that multicast outperforms multiple-unicast only when the average SNR is above a given threshold. The main reason is that multicast scheduling has to consider the worst SNR of the group of users as opposed to multiple-unicast scheduler that can choose at each TTI the user that has the best SNR. Users with low SNR are generally on the cell border and may generally receive several base stations (BSs). It is then interesting to combine transmissions of neighboring BSs to increase the overall received SNR. Note that the multicast service is not restricted to one cell but can be delivered over several cells. In this context, the same data transport block (TB) is transmitted by several BSs. A UE may decode data from these BSs simultaneously. If at least one copy of the same TB is correctly received, this block is then considered successfully transmitted. By extending the TB level to the signal level, we identify this scheme as Selective Combining (SC) where a user selects the block with the maximum SNR. Alternatively, the receiver may combine replicas of the same flow proportionally to their strength like in Chase Combining (CC)

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(cha, ). The CC is a scheme of hybrid ARQ protocol that is used in High Speed Downlink Packet Access (HSDPA). With CC protocol, if an initial transmission is received with some errors, the corrupted data packet is stored at the terminal and retransmissions of identical coded data packets occur till a successful reception. Then, the decoder combines these multiple copies weighted by the SNR prior to decoding. This method provides diversity (time) gain. We propose to use the same principle but with copies of the same data block sent by different BSs. Extending the block level to the physical level amounts to the Maximal Ratio Combining (MRC) scheme where redundant signals are also combined proportionally to their strength. The resulting SNR is then the sum of the all received SNRs (eur, ). Conventional MRC (at the signal level) with MBMS has been studied in other papers, e.g. (Soares and Correia, 2006).

Our objective is to quantify the throughput gain of applying macro diversity combining schemes to multicast scheduling. Our multicast scheduler is called the equal-bitrate scheduler; it allocates bandwidth to mobiles according to their instantaneous channel quality. The multicast scheduler is based on a new clustering strategy. Clustering is the way to define sub-groups of users, all of them subscribing to the same service. The new clustering method combines multicast and unicast schemes according to the user's average channel conditions. We have developed it for a single cell case in (El Heni and Lagrange, 2008a) but it will be explained here again for the sake of clarity. This paper is organized as follows. In Section 2, the system model and assumptions are given. In Section 3, we define the new clustering strategy. Section 4 explains the proposed equal-bitrate scheduler and expands the scheduler model with the use of SC and MRC. Section 5 gives the simulation results. Conclusions are drawn in Section 6.

## 2 MODEL DESCRIPTION

### 2.1 General Considerations

In a regular cellular network, each cell has 6 neighboring cells. In a first approach, a cell may be divided in 6 sectors, each of which having one serving base station and one neighboring one. We restrict our study to one sector. Let BS1 be the serving base station and BS2 the neighboring one. This case is easily generalized to the whole cell if we consider that fading values in each sector are independent and then the system is invariant by rotation. We consider $N$ users that are randomly distributed in the studied sector represented by the shaded area $S_1$ in Figure 1. Users are listening to BS1 and BS2 separated by a distance $D_{1,2}$. Considering an hexagonal model

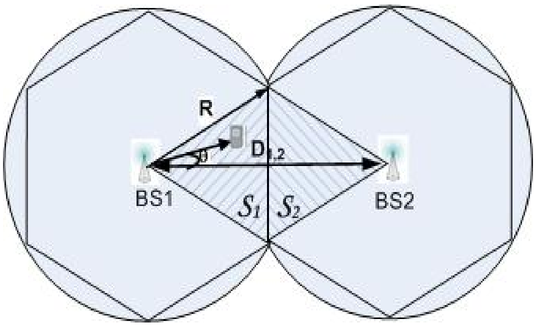

Figure 1: Macro diversity with 2 cells.

$$D_{1,2} = \sqrt{3}R \tag{1}$$

where $R$ is the cell radius. Large-scale mobility aspects and time constraints are not considered. Let $\gamma_{s,i,j}$ be the SNR of signal received by UE $i$ from BS $s$ within cluster $j$ and $\overline{\gamma_{s,i,j}}$ its average value. Due to channel variations, $\gamma_{s,i,j}$ are identical and independent distribution (iid) variables that change randomly from one TTI to another. The SNR is assumed to be constant during a TTI. Let $\gamma_{ij}$ be the instantaneous SNR after macro diversity combining at user $i$, which is member of cluster $j$. We denote $G$ as the number of clusters and $S_j$ the size of cluster $j$. We define $\beta_{ij}$ as the largest TBS supported by UE $i$. Let $g$ be the function that relates $\beta_{i,j}$ to the reported $\gamma_{i,j}$ of the served user $i$, hence

$$\beta_{ij} = g(\gamma_{i,j}). \tag{2}$$

It is easy to see that $g$ is a strictly increasing function. Let $h$ be the associated inverse function: $\gamma_{i,j} = h(\beta_{i,j})$. Finally, we define $\gamma_j$ as the selected SNR for cluster $j$ and $R_j$ the mean bitrate of cluster $j$. Indices $i$, $j$ and $s$ may be sometimes omitted for simplicity.

We consider only one multicast group, i.e. all users in the serving cell listen to the same service. Scheduling multiple services amounts to managing priority between these services according to their QoS requirements. These issues have been extensively developed in literature (Lundevall et al., 2004), (Kazmi and Wiberg, 2003) and are out of the scope of our study.

### 2.2 Propagation Model

The average SNR received by a UE may be computed by using a conventional propagation model. The model is explained via one BS. Let $P_i$ be the transmit power to user $i$. The received power, denoted as $P_r$, is then given by

$$P_r = P_i h_i \chi_i \tag{3}$$

where $h_i$ is the path gain including shadowing, distance loss and antenna gain between user $i$ and the BS and $\chi_i$ is the fast fading between user $i$ and the BS. Variable $\chi_i$ is a random variable which represents Rayleigh fast fading. It therefore has an exponential distribution. The signal to interference ratio received by user $i$ is

$$\gamma_i = \frac{P_i h_i \chi_i}{\alpha(P_{max} - P_i) h_i \chi_i + I_{ext}} \tag{4}$$

where $P_{max}$ is the total transmit power of the cell, $\alpha$ is the orthogonality factor and $I_{ext}$ represents the inter-cell interference. The average SNR of user $i$ located at a distance $d$ from the BS is given by

$$\overline{\gamma}_i(d) = \int_0^{\gamma_{sup}} \exp\left(\frac{-I_{ext} 10^{\frac{A_0}{10}} d^{\beta} x}{P_i - \alpha(P_{max} - P_i)x}\right) dx \tag{5}$$

where $\beta$ is the pathloss exponent, $A_0$ is the distance-loss at 1 m (with a BS antenna height of 30 m, a UE antenna height of 1.5 m and a carrier frequency of 1950 MHz) and $\gamma_{sup}$ is defined by

$$\gamma_{sup} = \frac{P_i}{\alpha(P_{max} - P_i)}. \tag{6}$$

## 3 PROPOSED CLUSTERING STRATEGY

Clustering is the way to define sub-groups of users, all of them subscribing to the same service. We propose a new clustering method called *mixed clustering*; it combines multicast and unicast schemes according to the user's average channel conditions. We have seen in (El Heni and Lagrange, 2008b) that multicast outperforms multiple-unicast only for high average SNRs (above around 3.7 dB). Our clustering scheme is then deduced as illustrated in Figure 2:

- An average SNR threshold is fixed so that the system can differentiate users. The average SNR is declared as "low" if it is below a threshold value denoted as $\overline{\gamma}_{thres}$. Let $N_{low}$ be the number of users having a low average SNR.
- Users with low average SNRs have to be separated from each other. In fact, if the cluster size increases for low SNR values, the instantaneous bitrate capacity within the cluster becomes lower as the multicast strategy is conservative. Our solution is to serve these users according to a unicast scheme.
- Users with high average SNRs should follow a multicast scheme. They are grouped in the same cluster which contains $N - N_{low}$ users. Consequently, the resulting number of clusters $G$ is equal to $N_{low} + 1$. Of course, if all users have low average channel quality, $G$ is equal to $N_{low}$.

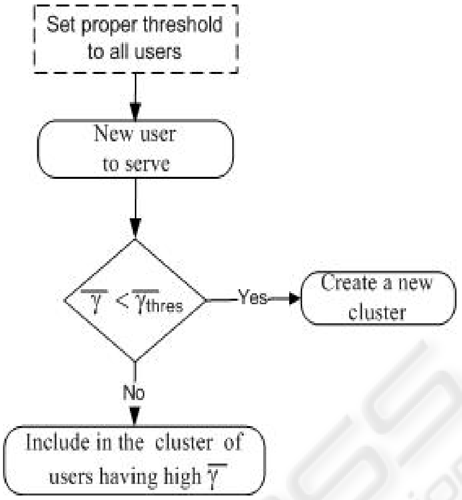

Figure 2: Proposed clustering strategy.

## 4 MULTICAST SCHEDULING WITH SC AND MRC

### 4.1 Proposed Multicast Scheduler

In this study, we propose a scheduling scheme called the equal-bitrate scheduler. It aims at increasing fairness among multicast clusters while offering good system throughput. Equal-bitrate scheduling is performed in two steps. First, the scheduler determines the convenient transmission bitrate for each cluster. The intra-cluster bitrate allocation strategy is conservative. We have then

$$\gamma_j = \min_{i=1..S_j} \gamma_{i,j}(t). \tag{7}$$

We denote $P_X(x)$ as the cumulative distribution function (CDF) of a random variable $X$. Similarly, $p_X(x)$ denotes the probability distribution function (PDF) of $X$. Hence, the CDF of $\gamma_j$ is equal to

$$P_{\gamma_j}(x) = 1 - \prod_{i=1}^{S_j} \left(1 - P_{\gamma_{i,j}}(x)\right). \tag{8}$$

Once the bitrate of each cluster is determined, the scheduler chooses the cluster to serve. In order to maximize the global throughput, a natural solution is to serve the cluster having the highest bitrate capacity. However, the scheduling must guarantee fairness between clusters. This may be achieved by realizing

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the same average bitrate for all the clusters. For this purpose, we define fairness factors $M_{j=1..G}$ such that the scheduler serves the cluster having a higher bitrate capacity with a lower probability, *i.e.* time is not uniformly shared between clusters. At instant $t$, cluster $j$ is served if the product of its instantaneous SNR and its corresponding fairness factor $M_j$ is the highest among all the clusters; hence, if and only if

$$\gamma_j M_j = \max_{l=1..G}(\gamma_l M_l). \tag{9}$$

It can be established that the mean bitrate used to serve cluster $j$ is

$$R_j = \frac{1}{D_{TTI}} \int_0^\infty \left[ p_{\gamma_j}(x) g(x) \prod_{l=1,l\neq j}^{G} P_{\gamma_l}\left(\frac{xM_j}{M_l}\right) \right] dx \tag{10}$$

where $D_{TTI}$ is the TTI duration. Equation (10) gives a general formula for the average bitrate per cluster $j$ once the clusters are made. Note that this formula depends on $\{M_j\}$. The value of $\{M_j\}_{j=1..G}$ is fixed so that $\forall j = 2..G$, $R_1 = R_j$; with $M_1$=1. The value of $G$ is determined by the clustering scheme detailed in Section 3.

In the context of multiple-unicast, $N$ single-user clusters are considered. The individual mean bitrate is derived from (10) for $G = N$ ($S_j = 1\ \forall j = 1..G$).

$$R_j = \frac{1}{D_{TTI}} \int_0^\infty \left[ p_{\gamma_j}(x) g(x) \prod_{l=1,l\neq j}^{N} P_{\gamma_l}\left(\frac{xM_j}{M_l}\right) \right] dx. \tag{11}$$

In the framework of pure multicast, the average bitrate denoted as $R_{mcast}$ is derived from (10) for $G$=1. After a few computation, we obtain

$$R_{mcast} = \frac{1}{D_{TTI}} \int_0^\infty \left( \prod_{i=1}^{N} [1 - P_{\gamma_i}(h(x))] \right) dx. \tag{12}$$

### 4.2 SC with Multicast Scheduling

According to selective combining, a user selects the data bloc yielding the highest SNR. We have then

$$\gamma_{i,j} = \max_{s=1..S}(\gamma_{s,i,j}) \tag{13}$$

where $S$ is the number of BSs received by a user (in the framework of this study $S = 2$). The CDF of $\gamma_{i,j}$ is given by

$$P_{\gamma_{i,j}}(x) = \prod_{s=1}^{S} P_{\gamma_{s,i,j}}(x). \tag{14}$$

Combining equations (8), (10) and (14), we have the average bitrate per cluster with SC and denoted as $R_{j,SC}$

$$R_{j,SC} = \frac{1}{D_{TTI}} \int_0^\infty [p_{\gamma_j}(x) g(x) \prod_{l=1,l\neq j}^{G} \tag{15}$$
$$[1 - \prod_{i=1}^{S_l}(1 - \prod_{s=1}^{S} P_{\gamma_{s,i,l}}(\frac{xM_j}{M_l}))]] dx.$$

### 4.3 MRC with Multicast Scheduling

The case of MRC is more complex than SC. In fact, as terminals combine the different transmissions proportionally to their strength, the resulting SNR for user $i$ is given by (eur, )

$$\gamma_{i,j} = \sum_{s=1..S} \gamma_{s,i,j}. \tag{16}$$

The CDF of the SNR for user $i$ is given by

$$P_{\gamma_{i,j}}(x) = Pr(\sum_{s=1..S} \gamma_{s,i,j} \leq x) \tag{17}$$

When $S$=2, we define $\delta_{i,j}$ as follows

$$\delta_{i,j} = \overline{\gamma_{2,i,j}} - \overline{\gamma_{1,i,j}}. \tag{18}$$

The CDF of $\gamma_{i,j}$ is given by

$$P_{\gamma_{i,j}}(x) = \frac{-\overline{\gamma_{2,i,j}} \exp(\frac{-x}{\overline{\gamma_{2,i,j}}}) + \overline{\gamma_{1,i,j}} \exp(\frac{-x}{\overline{\gamma_{1,i,j}}}) + \delta_{i,j}}{\delta_{i,j}}. \tag{19}$$

Then, the average bitrate per cluster for MRC and denoted as $R_{j,MRC}$ can be easily deduced for $S = 2$ if equations (8), (10) and (19) are combined.

$$R_{j,MRC} = \frac{1}{D_{TTI}} \int_0^\infty p_{\gamma_j}(x) g(x) \prod_{l=1,l\neq j}^{G} [1 - \prod_{i=1}^{S_l} \tag{20}$$
$$(1 - \frac{-\overline{\gamma_{2,i,l}} \exp(\frac{\frac{-xM_j}{M_l}}{\overline{\gamma_{2,i,l}}}) + \overline{\gamma_{1,i,l}} \exp(\frac{\frac{-xM_j}{M_l}}{\overline{\gamma_{1,i,l}}}) + \delta_{i,l}}{\delta_{i,l}})] dx.$$

### 4.4 Application to a Generic System

In (Knopp and Humblet, 1995), it was proposed a reference radio channel model based on an exponential distribution for $\gamma$. Hence

$$P_\gamma(x) = 1 - \exp(-x/\overline{\gamma}) \quad \text{if } x > 0. \tag{21}$$

Supposing that each signal received by a UE follows an exponential distribution for the SNR, equation (15) is reformulated as follows

$$R_{j,SC} = \frac{1}{D_{TTI}} \int_0^\infty [p_{\gamma_j}(x) g(x) \prod_{l=1,l\neq j}^{G} \tag{22}$$
$$[1 - \prod_{i=1}^{S_l}(1 - \prod_{s=1}^{S}[1 - \exp(-\frac{xM_j}{M_l \overline{\gamma_{s,i,j}}})])]] dx.$$

Table 1: Simulation parameters.

| | |
|---|---|
| Frame period | 2 (ms) |
| BS Transmission power | 38 (dBm) |
| Intra-cell interference | 30 (dBm) |
| Inter-cell interference | -100 (dBm) |
| $\beta$ | 3.52 |
| $A_0$ | 31.8 (dB) |
| $W$ | 5 (MHz) |

In the case of pure multicast, equation (12) is rewritten for SC as follows

$$R_{mcast,SC} = \frac{1}{D_{TTI}} \int_0^\infty \prod_{i=1}^{N} (1 - \prod_{s=1}^{S} [1 - \exp \frac{-h(x)}{\overline{\gamma_{s,i}}}]) dx. \tag{23}$$

as for multiple-unicast with SC, equation (11) is rewritten as follows

$$R_{j,SC} = \frac{1}{D_{TTI}} \int_0^\infty p_{\gamma_j}(x) g(x) \prod_{l=1,l\neq j}^{N} \prod_{s=1}^{S} [1 - \exp(\frac{-xM_j}{M_l \overline{\gamma_{s,l}}})] dx \tag{24}$$

Function $g$ is given by Shannon formula (Shannon, 1948): $g(\gamma_i) = WD_{TTI} \log_2(1+\gamma_i)$ where $W$ is the available bandwidth. Function $h$ is then $h(x) = 2^{x/WD_{TTI}} - 1$.

In the context of MRC with pure multicast, equation (12) is rewritten for $S=2$ as follows

$$R_{mcast,MRC} = \frac{1}{D_{TTI}} \int_0^\infty \prod_{i=1}^{N} (1 - \frac{-\overline{\gamma_{2,i,j}} \exp(\frac{-h(x)}{\overline{\gamma_{2,i,j}}}) + \overline{\gamma_{1,i,j}} \exp(\frac{-h(x)}{\overline{\gamma_{1,i,j}}}) + \delta_{i,j}}{\delta_{i,j}}) dx. \tag{25}$$

As for MRC with multiple-unicast, we combine equations (11) and (19) as follow

$$R_{j,MRC} = \frac{1}{D_{TTI}} \int_0^\infty [p_{\gamma_j}(x) g(x) \prod_{l=1,l\neq j}^{N} \frac{-\overline{\gamma_{2,l}} \exp(\frac{-xM_j}{\overline{\gamma_{2,l}} M_l}) + \overline{\gamma_{1,l}} \exp(\frac{-xM_j}{\overline{\gamma_{1,l}} M_l}) + \delta_{i,j}}{\delta_{i,j}}] dx. \tag{26}$$

# 5 EVALUATION RESULTS

In this section , we evaluate the gain of macro diversity techniques for different clustering schemes, namely mutliple-unicast, pure multicast and mixed clustering. Simulation parameters are listed in Table 1. We perform 120 iterations with different user distributions. Only one multicast service is considered. We evaluate results for 5 and 10 randomly distributed users located in cell 1 and listening to BS1 and BS2 ($S$=2). As we restrict ourselves to one service and one cell, these numbers remain reasonable. In the case of mixed multicasting, we fix $\overline{\gamma}_{thres}$ to 3.7 dB as found in (El Heni and Lagrange, 2008b). Results of the average bitrate performance for SC with the 95% confidence intervals are depicted in Table 2. We see that macro diversity using SC improves the system performance. Gains for pure multicasting are of 20% and 18% for 5 and 10 UEs, respectively. In fact, the performance of this scheme depends only on the lowest SNR value; as the SC technique increases the channel quality particularily for users at the cell border (*i.e.* having the lowest SNR), it has a direct impact on the pure multicast scheduler. In the case of mixed clustering, gains are of 8.5% and 6.5% for 5 and 10 UEs, respectively. With multiple-unicast, the gain is of 7% and 5% for 5 and 10 UEs, respectively. Gains of macro diversity with multiple-unicast and mixed clustering are lower than those obtained for pure multicast. In fact, users with the lowest SNRs are served in a unicast scheme and increasing their average channel quality allows a better bitrate capacity for these users, the impact on the global system is less visible. SC allows users with higher SNRs to be served more frequently as the deviation between the lowest and the highest average SNR is cut off. Results for Maximum Ratio Combining are depicted in Table 3. Achieved gains are higher than those achieved with MRC. Gains for pure multicasting are of 31% and 28% for 5 and 10 UEs, respectively. In the case of multiple-unicast, gains are of 12% and 9% for 5 and 10 UEs, respectively. As for mixed clustering, gains are of 15.5% and 14% for 5 and 10 UEs, respectively. It is noteworthy that when $N$ increases, user location tend to concentrate in the middle of the cell where the signal level is quite high. This is the reason for the decrease of macro diversity gain.

# 6 CONCLUSIONS

In this study, we consider macro diversity in the framework of multicast scheduling over high-speed networks. We have developed an analytical model for the mean bitrate calculations in order to evaluate the resulting scheduling performance. To ensure an optimal usage of our scheduler, we have used a clustering strategy that classifies terminals according to their average channel quality. We have shown that macro diversity using selective combining and maximum ratio combining improves the system performance. The study shows that the macro diversity gain

Table 2: Throughput (bps) with confidence intervals for different clustering strategies with/without SC.

| Strategy | *N* | without SC | with SC | SC Gain |
|---|---|---|---|---|
| Pure multicast | 5 UEs | $4.28\ 10^6 \pm 3.8\%$ | $5.14\ 10^6 \pm 4\%$ | 20% |
| | 10 UEs | $3.33\ 10^6 \pm 4\%$ | $3.92\ 10^6 \pm 5\%$ | 18% |
| Multiple-unicast | 5 UEs | $3.47\ 10^6 \pm 3\%$ | $3.71\ 10^6 \pm 2.3\%$ | 7% |
| | 10 UEs | $2.45\ 10^6 \pm 3.5\%$ | $2.57\ 10^6 \pm 2\%$ | 5% |
| Mixed strategy | 5 UEs | $5.07\ 10^6 \pm 2.9\%$ | $5.49\ 10^6 \pm 2.8\%$ | 8.5% |
| | 10 UEs | $4.19\ 10^6 \pm 3.4\%$ | $4.45\ 10^6 \pm 2.9\%$ | 6.5% |

Table 3: Throughput (bps) with confidence intervals for different clustering strategies with/without MRC.

| Strategy | *N* | without MRC | with MRC | MRC Gain |
|---|---|---|---|---|
| Pure multicast | 5 UEs | $4.28\ 10^6 \pm 3.8\%$ | $5.60\ 10^6 \pm 4\%$ | 31% |
| | 10 UEs | $3.33\ 10^6 \pm 4\%$ | $4.31\ 10^6 \pm 2.8\%$ | 28% |
| Multiple-unicast | 5 UEs | $3.47\ 10^6 \pm 3\%$ | $3.82\ 10^6 \pm 3.4\%$ | 12% |
| | 10 UEs | $2.45\ 10^6 \pm 3.5\%$ | $2.67\ 10^6 \pm 3.3\%$ | 9% |
| Mixed strategy | 5 UEs | $5.07\ 10^6 \pm 2.9\%$ | $5.85\ 10^6 \pm 2.6\%$ | 15.5% |
| | 10 UEs | $4.19\ 10^6 \pm 3.4\%$ | $4.78\ 10^6 \pm 3\%$ | 14% |

is the highest for the pure multicast scheme. Considering multiple-unicast and mixed clustering, we obtain equivalent results.

To exploit efficiently the advantages of macro diversity, some optimizations have to be considered in relation with the feedback procedure and retransmission management. This could be considered in a future work.

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